CHAPTER 12

NORTHERN ROCKFISH

by

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Executive Summary

The following changes were made to northern rockfish assessment relative to the November 2003 SAFE:

Changes in the Input Data

(1) The 2003 harvest level has been revised and harvests through October 2, 2004 have been included in the assessment.

(2) The survey biomass and length composition from the 2004 AI survey were included in the assessment.

(3) The 2000 and 2003 age composition from the Aleutian Islands (AI) fishery was included in the assessment.

Changes in Assessment Methodology

(1) The growth curve and transition matrix were re-estimated to account for length-stratified sampling of otoliths in the eastern Bering Sea trawl survey.

(2) The survey catchability coefficient was fixed at 1.0.

Changes in the Assessment Results

A summary of the 2004 assessment recommended ABC's relative to the 2003 recommendations is as follows:

	Assessment Year	
	2004	2003
ABC	8,260 t	6,881 t
OFL	9,813 t	8,136 t

Responses to the Comments of the Statistical and Scientific Committee (SSC)

From the December, 2003, minutes: "*Given the small sample size upon which the genetic determination was made, the SSC requests that additional genetic analysis be conducted to achieve a more solid basis for apportionment decisions*" Tissues from northern rockfish were collected from each of the four major areas in the 2004 Aleutian Islands survey (100 samples each), as well as 100 samples from the 2004 EBS slope survey. A genetic analysis of these samples will be pursued in the future.

INTRODUCTION

Northern rockfish (*Sebastes polyspinus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Northern rockfish (*Sebastes polyspinus*) in the Bering Sea/Aleutians Islands (BSAI) region have been assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP until 2004, and have historically relied solely upon recent survey biomass estimates for an estimation of stock size. The reading of archived otoliths from the AI surveys allowed the development of an age-structured model for northern rockfish beginning in 2003.

Information on Stock Structure

A variety of types of research can be used to infer stock structure of northern rockfish, including larval distribution patterns and other life-history information, and genetic studies. In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999, primarily in the Gulf of Alaska). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicates that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most are small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (POP), *S. polyspinus* (northern rockfish), and *S. ciliatus* (dusky rockfish).

An initial genetic analysis revealed no evidence of population structure in Alaskan northern rockfish from either mtDNA or microsatellite analysis (Gharrett 2003), based upon small samples of 20 fish from each of three locations (Kodiak Island, Unimak Pass, and Stalemate Bank). Although the sample sizes were small and had little power, the authors concluded that the analysis was sufficient to conclude that existing structure is not pronounced. However, this study looked at only a portion of the mtDNA genome and a handful of microsatellite loci, and had small sample sizes. Also, the failure to identify population structure does not necessarily imply that northern rockfish consist of a single population unit. If subtle differences occur, much larger sample sizes would be required in order to identify stock structure.

FISHERY

BSAI foreign and joint venture rockfish catch records from 1977 to 1989 are available from foreign "blend" estimates of total catch by management group, and observed catches from the North Pacific Observer Program database. The foreign catch of BSAI rockfish during this time was largely taken by Japanese trawlers, whereas the joint-venture fisheries involved partnerships with the Republic of Korea. Because northern rockfish are taken as bycatch in the BSAI area, historical foreign catch records have not identified northern rockfish catch by species. Instead, northern rockfish catch has been included in a variety of management categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988). Foreign harvest was calculated by estimating the species composition of observed catches from the North Pacific Observer Program database, and applying those estimates to the "blend" estimates of total catch of the appropriate management category.

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. From 1991 to 2000, northern rockfish harvest in the EBS was included in the "other red rockfish" category, whereas harvest in the Aleutian Islands was reported in a "northern/sharpchin" category. In 2001, northern rockfish in the EBS were managed in a "northern/sharpchin" category, matching the species complex in the AI, and the management was combined across the BSAI area. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. Estimates of domestic catch since 1991 were made in a similar manner as the foreign catches. Estimates of domestic catch in 1990 were obtained from Guttormsen et al 1992. Northern rockfish catches from the domestic fishery prior to the start of the domestic observer program were obtained from PACFIN records.

Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977) (Table 12.1). Harvest data from 2000-2003 indicates that approximately 90% of the BSAI northern rockfish are harvested in the Atka mackerel fishery, with a large amount of the catch occurring in September in the central and western Aleutians (areas 542 and 543). The distribution of northern rockfish harvest by Aleutian Islands subarea reflects both the spatial regulation of the Atka mackerel fishery and the increased biomass of northern rockfish in the western Aleutian Islands. Northern rockfish are patchily distributed and are harvested in relatively few areas within the broad management subareas of the Aleutian Islands, with important fishing grounds being Petral Bank, Sturdevant Rock, south of Amchitka I., and Seguam Pass (Dave Clausen, NMFS-AFSC, personal communication). The removals of northern rockfish from the trawl and hydoracoustic surveys are shown in Table 12.2.

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discard. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. The discards rates are generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 12.3). The recent discard rates in the Aleutian Islands have been high, over 97% in both 2001 and 2002.

DATA

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 12.4). In some years, such as 1984 and 1987 over 700 fish lengths were obtained but these data samples came from a limited number of hauls. Additionally, the length data from the foreign fishery tended to originate from predominately one location in each year, and was not consistent between years. For example, the 1977 and 1978 fishery length data were collected from Tahoma Bank in the western Aleutians, whereas samples in 1984 were obtained from Seguam Pass and samples in 1987 were obtained from Petral Bank. In the domestic fishery, changes in observer sampling protocol since 1999 improved the distribution of hauls from which northern rockfish age and length data were collected.

In this assessment annual length frequency data were selected on the basis of consistency in sampling location and the number of samples collected. Foreign fishery length data from 1977 and 1978 were used, in part, because of the consistency in their sampling location, the increased numbers of hauls from which they were obtained, and the absence of other length composition data during this portion of the time series. Domestic fishery length data from 1996, 1998-1999, and 2001 are used, and the length and age data from 2000, and 2002-2003 are used to construct an estimated age-frequency of the fishery catch.

Survey data

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys, conducted by the National Marine Fisheries Service (NMFS) were conducted in 1988 and 1991 on the eastern Bering Sea slope, and in 1991, 1994, 1997, 2000, 2002, and 2004 in the Aleutian Islands (Table 12.5). Previous assessments have determined northern rockfish biomass by averaging recent survey results, thus placing considerable weight upon the biomass estimate from each year. The AI cooperative surveys during the 1980s were not used in previous assessments due to the more recent information from the NMFS trawl surveys, and also differences in vessels and gear design from the U.S. domestic surveys (Skip Zenger, National Marine Fisheries Service, pers. comm.). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys.

In this assessment, the AI surveys from the 1980s are used to provide some indication of biomass during this time period. The survey time series beginning in 1980 is considered as one data set, and no attempt is made to estimate a separate catchability coefficient for the cooperative surveys in the 1980s. In future assessments, the feasibility of reanalyzing the data from the cooperative surveys will be investigated, which would involve estimating fishing power corrections and re-estimating biomass levels and survey length with current (post 1990) survey strata. For the current assessment, the inclusion of the age and length composition data and catch data reduces the degree of influence of these biomass estimates (relative to an averaging of biomass estimates), as does the rather large standard deviations of estimated biomass; for example, the coefficient of variation (CV) ranges between 0.36 in 1983 to 1.3 in 1980 (Table 12.5).

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, and previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. The 2002 EBS slope survey northern rockfish biomass estimate and its coefficient of variation were 33 t and 0.38, respectively, and the 2004 biomass estimate and it coefficient of variation were 16 t and 0.41, respectively. As in the BSAI POP assessment, the slope survey results are not used in this assessment and the 1991-2004 Aleutian Islands trawl surveys are considered an index of the BSAI population. The feasibility of incorporating EBS slope survey time series will be evaluated in future years.

The biomass of northern rockfish is concentrated largely in the western Aleutian Islands, with an average of 73% of the estimated biomass from the 1991-2004 NMFS AI trawl surveys occurring in this region (Table 12.5). The coefficients of variation (CV) of these biomass estimates by region are generally high, but especially so in the southern Bering Sea portion of the surveyed area (165 W to 170 W), where the CV was less than 0.60 only in the 2000 survey.

Biological Data

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of otoliths collected and lengths measured are shown in Table 12.6, along with the number of hauls producing these data. The survey data produce reasonable sample sizes of lengths and otoliths from throughout the survey area. The maximum age observed in the survey samples was 72 years.

The survey otoliths were read with the break and burn method, and were thus considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from Courtney et al. 1991, based on two independent readings of otoliths from the Gulf of Alaska trawl survey from 1984-1993. The raw data in Courtney et al. (1999) was used to estimate the standard deviation for each age assigned by one reader, and it was assumed the age assigned by the other reader was accurate. The standard deviations were regressed against age to provide a predicted estimate of standard deviation of observed ages for a given true age, and this linear relationship was used to produce the aging error matrix is shown in Table 12.7.

In previous assessments, information regarding growth of northern rockfish was produced by fitting a von Bertalanffy curve to the available length-at-age data from all specimens sampled in trawl surveys. However, such data are typically obtained from length-stratified sampling, thus potentially introducing some bias into estimates of length at age (Kimura and Chikuni 1987). Additonally, previous assessments have shown differences in the length-at-age curves from the three management area within the Aleutian Islands, and the development of a single length-at-age curve representing all areas should consider the different population sizes between the areas. In this assessment, in each Aleutian Island management area the estimated population numbers at length was multiplied by the age-length key in order to produce a matrix of estimated population numbers by age and length, from which an unbiased average length for each age can be determined. A single average length at age was obtained by taking an average of the three estimates (weighted by population size). This procedure was applied to the 1997 and 2000 data; the samples sizes of otoliths by area in previous years are not sufficient to conduct this procedure in previous years (Table 12.8).

The resulting length-at-age curve obtained from the 2000 AI survey is similar to the length at age curve used in the 2003 assessment, which was based upon directly using all available samples from Aleutian Island surveys (Figure 12.1). A comparison of the von Bertalanffy parameters between these two curves is shown below. The length-at-age-curve derived from the 2000 survey was used in this assessment to create a transition matrix and a weight-at-age vector; the length-at-age curve derived from the 1997 survey (not shown) was very similar.

Assessment	L_{inf}	**K**	t_0
2003 assessment	33.79	0.19	-0.016
2004 assessment	34.39	0.18	-0.2659

A transition matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin (Table 12.9). This matrix was created by regressing the observed standard deviation in length at each age (obtained from the aged fish from the 1986-2000 surveys) against age, and the predicted relationship was used to produce some variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.16 at age 3 to 0.12 at age 23.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1986-2000, and produced estimates of $a = 1.25 \times 10^{-5}$ and $b = 3.05$. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 12.10).

In recent years, the proportion of northern rockfish in large size bins has been less in the AI survey relative to samples obtained in the fishery (Figure 12.2), and it will be seen later that this pattern influences the estimated fishery selectivity curve.

The following table summarizes the data available for the BSAI northern rockfish model:

Component	BSAI
Fishery catch	1977-2004
Fishery age composition	2000, 2002-2003
Fishery size composition	1977, 1978, 1996, 1998-1999, 2001
Survey age composition	1991, 1994, 1997, 2000, 2002
Survey length composition	2004
Survey biomass estimates	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004

ANALYTIC APPROACH

Model structure

The assessment model for northern rockfish is very similar to that currently used for BSAI Pacific ocean perch, which was used as a template for the current model. Population size in numbers at age *a* in year *t* was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 \le a < A, \quad 1977 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 23), and T is the terminal year of the analysis (defined as 2004). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The numbers at age in the first year are estimated as

$$N_a = R_0 e^{-M(a-3)+\gamma_a}$$

where R_0 the number of age 3 recruits for an unfished population and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_r, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 1997 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν_t is a time-variant deviation. The recruitments from 1998 to 2004 are set the median recruitment, e^{μ_r}.

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) that increases asymptotically with age and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishsel_a * f_t \equiv fishsel_a * e^{(\mu_f + \varepsilon_t)}$$

The logistic curve is used to model fishery selectivity at age:

$$fishsel_a = \frac{1}{1 + \exp(-slope(a - a_{50\%}))}$$

where the $a_{50\%}$ and *slope* parameters control the age at 50% maturity and the slope of the curve at this point, respectively.

Initial model runs indicated that the age of 50% selectivity in the fishery was about 15 years. This result stems from the greater proportion of fish in the larger size bins in the fishery length composition relative to the survey length composition (Figure 12.2). Estimates of survey selectivity, also modeled with a logistic curve, show a much lower age at 50%

selectivity, and it is not expected that the fishery selectivity would differ substantially from the survey selectivity. The fishing selectivity parameters were estimated as the survey selectivity parameters multiplied by e^{γ}, where γ was normally distributed with a mean of zero and a standard deviation of 0.03 and 0.05, respectively, for the $a_{50\%}$ and *slope* parameters, respectively.

The mean numbers at age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred\_biom_t = qsurv \sum_a \left(\overline{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability.

To facilitate parameter estimation, prior distributions were used for the survey catchability the natural mortality rate *M*. A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.06 (the value used in previous assessments, based upon expected relationships between *M*, longevity, and the von Bertalanffy growth parameter *K* (Alverson and Carney 1975)) and the CV set to a 0.25. The standard deviation of log recruits, σ_r, was also modeled with a prior lognormal distribution, although the CV was set so low (0.001) so as to essentially fix this parameter at a constant level. This choice was motivated by the increased potential for model instability when variance parameters are estimated, and σ_r was set to 0.75, consistent with previous assessments. Similar, the prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.001, essentially fixing *qsurv* at 1.0.

Parameters Estimated Independently

The parameters estimated independently include the age error matrix, the age-length transition matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector are described above. The proportion of females mature at age (Table 12.10) was obtained from the Gulf of Alaska northern rockfish model (Courtney et al. 1999), and a logistic curve was fit to data collected by Chris Lunsford of the Auke Bay Laboratory.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that maximize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2}\right)^2}{2\sigma^2} + n\ln(\sigma)$$

The adjustment of adding $\sigma_r^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment. The log-likelihood of the recruitment of cohorts represented in the first year of the model treated in a similar manner:

$$\lambda_1 \sum_{a-1} \frac{(\gamma_t)^2}{2\sigma^2} + (a-1)\ln(\sigma)$$

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l})$$

where n is the number of hauls that produced the data, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 \;/\; 2cv_t^{\,2}$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the *F* levels, and the deviations in *F* are not included in the overall likelihood function. The overall negative log-likelihood function (excluding the catch component) is

$$\lambda_1\left(\sum_t\left(\frac{\nu_t+\sigma^2/2}{2\sigma^2}\right)^2+n\ln(\sigma)\right)+$$
$$\lambda_1\left(\sum_{a-1}\left(\frac{\gamma_t}{2\sigma^2}\right)^2+(a-1)\ln(\sigma)\right)+$$
$$\lambda_2\sum_t(\ln(obs\_biom_t)-\ln(pred\_biom_t))^2/2*cv_t^2+$$
$$n_{f,t,l}\sum_{s,t,l}p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l})+$$
$$n_{f,t,a}\sum_{s,t,l}p_{f,t,a}\ln(\hat{p}_{f,t,a})-p_{f,t,a}\ln(p_{f,t,a})+$$
$$n_{surv,t,a}\sum_{s,t,a}p_{surv,t,a}\ln(\hat{p}_{surv,t,a})-p_{surv,t,a}\ln(p_{surv,t,a})+$$
$$n_{surv,t,l}\sum_{s,t,a}p_{surv,t,l}\ln(\hat{p}_{surv,t,l})-p_{surv,t,l}\ln(p_{surv,t,l})+$$
$$\lambda_3\sum_t(\ln(obs\_cat_t)-\ln(pred\_cat_t))^2$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data. The sample sizes for the age and length compositions were set to the number of hauls from which these demographic data were obtained. Additionally, because of the difficulty in fitting a fishery selectivity curve to the fishery age and length data, these data components were assigned one-half the weight assigned to the survey age compositions. Initial models runs indicate that the recent total biomass is strongly influenced by the 1994 year class, which is predominately observed as 8 year-old fish in the 2002 survey age composition. Given the uncertainty of this relatively recent year class, the 2002 survey age composition was assigned a weight of one-half the number of hauls.

The negative log-likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_t)	28
3) recruitment mean (μ_r)	1
4) recruitment standard deviation (σ_r)	1
5) recruitment deviations (ν_t)	21
6) historic recruitment (R_0)	1
7) first year recruitment deviations	20
8) biomass survey catchability	1
9) natural mortality rate	1
10) survey selectivity parameters	2
11) fishery selectivity parameters	2
Total parameters	79

RESULTS

The negative log-likelihood associated with the various data components, and effective sample size for the age and size composition data, are shown in Table 12.11. The effective sample size can be interpreted as the sample size that would be consistent with the fit produced by the model, and data components where the effective sample size exceeds the input sample size can be interpreted as good fits. The effective sample size for the survey age and length composition were 82% and 49% of the input sample size, respectively, and the degraded fit for the survey length composition reflects that one year (2004) exists for this data component. The effective sample sizes for the fishery age and size compositions were 46% and 26% of the input sample sizes, reflectively, and as these data components were down-weighted relative to the survey age and length composition.

Biomass trends

The estimated survey biomass shows a slightly increasing trend, starting at 114,375 t in 1977 and increasing gradually to 177,253 t in 1998; the 2004 estimated survey biomass was 177,531 t (Figure 12.3). The total biomass and spawner biomass showed similar patterns as the survey biomass, with the 2004 estimates being 201,307 t and 66,896 t, respectively (Figure 12.4). The time series of estimated total biomass, spawner biomass, and recruitment are shown in Table 12.12.

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 12.5-12.6, and the model fit to the survey age and length compositions are shown in Figures 12.7- 12.8. The model captures the general trends in the survey age data, but does not completely match the magnitude of some of the peaks of these data. The estimated age at 50% selection for the survey and fishery selectivity curves were 7.07 and 7.64 years, respectively (Figure 12.9). Recall that the fishery selectivity parameters are constrained by the survey selectivity parameters, and the fishery selectivity curve would tend to a higher age at 50% selectivity if this restraint was not in place.

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 12.10. A relatively high rate in 1977 is required to account for the relatively high catch in this year, followed by very low levels of fishing mortality during the 1980s when catch was small. Fishing mortality rates began to increase during the early 1990s, and the 2004 estimate is 0.024. A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules indicates that the stock is currently below the $F_{35\%}$ and $B_{40\%}$ reference points (Figure 12.11).

Recruitment

Recruitment strengths by year class are shown in Figure 12.12. There is little information to discern strong recruitments in the early years of the model, although relatively strong year classes are observed in 1984, 1988,-1989, and 1993-1994. These year class strengths can be seen in the survey age composition data, where the 1984 year class is revealed in the 1991 and 1994 age composition data, the1989 year class is revealed in the 1997 and 2000 age composition data, and the 1993-1994 year classes are revealed in the 2000 and 2002 age composition data. The scatterplot of recruitment against spawning stock biomass is shown in Figure 12.13, indicating little variation in estimated spawning stock biomass but more substantial variation in estimated recruitment for the modeled years.

Projections and Harvest Alternatives

The reference fishing mortality rate for BSAI northern rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2001 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 45,912 t. The year 2005 spawning stock biomass is estimated as 66,588 t. Since reliable estimates of the 2005 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and B>$B_{0.40}$ (66,558 t > 45,912 t), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, the maximum permissible F_{ABC} is $F_{0.40}$, and F_{OFL} is constrained to be equal to $F_{0.35}$; the values of $F_{0.40}$ and $F_{0.35}$ are 0.048 and 0.058, respectively. The ABC associated with the $F_{0.40}$ level of 0.048 is 8,260 t. This ABC is approximately 1,379 t higher than last year's recommendation of 6,881 t, a 20% increase. The estimated catch level for year 2004 associated with the overfishing level of F = 0.058 is 9,813 t. A summary of these values is below.

2005 SSB estimate (B)	= 66,558 t
$B_{0.40}$	= 45,912 t
$F_{0.40}$	= 0.048
F_{ABC}	= 0.048
$F_{0.35}$	= 0.058
F_{OFL}	= 0.058

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2004 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2005 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2004. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2005, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

> *Scenario 4*: In all future years, F is set equal to the 1999-2003 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and five-year projections of the mean harvest and spawning stock biomass for the remaining four scenarios are shown in Table 12.13.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the northern rockfish stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2005, then the stock is not overfished.)
>
> *Scenario 7*: In 2005 and 2006, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2007 under this scenario, then the stock is not approaching an overfished condition.)

The projections of the mean spawning stock biomass, fishing mortality rate, and harvest for these scenarios are shown in Table 12.13. The results of these scenarios 6 and 7 indicate that the BSAI northern rockfish stock is neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2005 of scenario 6 is 1.65 times its $B_{35\%}$ value of 40,173 t. With regard to whether northern rockfish stock is likely to be overfished in the future, the expected stock size in 2007 of scenario 7 is 1.59 times the $B_{35\%}$ value.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Northern rockfish feed primarily upon zooplankton, including calanoid copepods, euphausids, and chaetonaths. From a sample of 118 Aleutian Island specimens collected in 1994, calanoid copepods, euphausids, and chaetonaths contributed 84% of the total diet by weight. Small northern rockfish (<30 cm FL) consumed a higher proportion of calanoid copepods than larger northern rockfish, whereas euphausids were consumed primarily by fish larger than 25 cm. Myctophids and cephalopods were consumed mainly by the largest size group, contributing 11% and 16%, respectively, of the diet for fish > 35 cm. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

Northern rockfish are not commonly observed in field samples of stomach contents. Pacific ocean perch, a rockfish with similar life-history characteristics as northern rockfish, has been found in the stomachs of Pacific halibut and sablefish (Major and Shippen 1970), and it is likely that these also prey upon northern rockfish as well. The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

Little information exists on the habitat use of northern rockfish. Carlson and Staty (1981) and Kreiger (1993) used submersibles to observe that other species of rockfish appear to use rugged, shallower habitats during their juvenile stage and move deeper with age. Although these studies did not specifically observe northern rockfish, it is reasonable to suspect a similar ontogenetic shift in habitat. Length frequencies of the Aleutian Islands survey data indicate that small northern rockfish (< 25 cm) are generally found at depths less than 100 m. The mean depth of northern rockfish from recent AI trawl surveys have ranged between 100 and 150 m. There has been little information identifying how rockfish habitat quality has changed over time.

Fishery Effects on the ecosystem

A northern rockfish target fishery does not currently exist in the BSAI management area. As previously discussed, most northern rockfish catch in the BSAI management area occurs in the Atka mackerel fishery. The ecosystem effects of the Atka mackerel fishery can be found in the Atka mackerel assessment in this SAFE document.

Harvesting of northern rockfish is not likely to diminish the amount of northern rockfish available as prey due to the low fishery selectivity for fish less than 20 cm. Although the recent fishing mortality rates have been relatively light, averaging 0.03 over the last five years, it is not know what the effect of harvesting is on the size structure of the population or the maturity at age.

SUMMARY

The management parameters for northern rockfish as presented in this assessment are summarized as follows:

Quantity	Value
M	0.050
Tier	3a
Year 2005 Total Biomass	200,013 t
Year 2005 Spawning stock biomass	66,558 t
$B_{100\%}$	114,780 t
$B_{40\%}$	45,912 t
$B_{35\%}$	40,173 t
F_{OFL}	0.058
Maximum F_{ABC}	0.048
Recommended F_{ABC}	0.048
OFL	9,813 t
Maximum allowable ABC	8,260 t
Recommended ABC	8,260 t

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Table 12.1. Catch of northern rockfish (t) in the BSAI area.

	Eastern Bering Sea			Aleutian Islands			
Year	Foreign	Joint Venture	Domestic	Foreign	Joint Venture	Domestic	Total
1977	4			3,232			3,236
1978	21			549			570
1979	61			195			256
1980	49	9		221			279
1981	20	0		92			112
1982	63	8		177	0		248
1983	10	32		47	0		89
1984	26	6		11	185		229
1985	5	1		0	189		195
1986	5	41	15	0	193	15	270
1987	1	45	31		248	60	385
1988		4	36		438	55	534
1989		12	66		0	306	384
1990			247			1,235	1,481
1991			614			233	847
1992			318			1,547	1,865
1993			859			4,530	5,389
1994			61			4,666	4,727
1995			266			3,858	4,124
1996			87			6,637	6,724
1997			164			1,996	2,161
1998			45			3,747	3,791
1999			157			5,492	5,650
2000			97			5,066	5,162
2001			180			6,309	6,488
2002			113			3,943	4,056
2003			72			4,582	4,653
2004*							4,166

*Catch data through October 2, 2004, from NMFS Alaska Regional Office.

Table 12.2. Estimated catch (t) of northern rockfish in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

		Area	
Year	AI	BS	BS-Hydroacoustic
1978		0.00	
1979		0.01	
1980	3.55	0.03	
1981		0.06	
1982	0.83	0.07	
1983	29.23	0.06	
1984		0.09	
1985		0.02	
1986	56.86	0.03	
1987		0.17	
1988		0.13	
1989		0.06	
1990		0.74	
1991	15.46	0.01	
1992		0.08	
1993		0.00	
1994	13.15	0.01	
1995			0.01
1996		0.00	
1997	17.67	0.03	0.03
1998		0.25	
1999		0.09	
2000	39.49	0.11	0.29
2001		0.04	
2002	36.34	0.02	0.32
2003		0.12	
2004	55.03	1.76	

Table 12.3. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NR), and northern rockfish catch in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The catches of the SC/NO group consist nearly entirely of northern rockfish. Prior to 2001, northern rockfish were managed as part of the ORR complex in the eastern Bering. Beginning in 2002, sharpchin rockfish were removed from other red rockfish and northern rockfish were managed with single-species catch levels. Unless otherwise noted, catch data were obtained from BLEND data and CAS data.

	Species		Catch (t)			
Area	Group	Year	Retained	Discard	Total	Percentage
EBS	SC/NO	2001	16	164	180	91.1%
EBS	Northerns	2002	9	105	113	92.4%
EBS	Northerns	2003	14	57	72	79.9%
AI	SC/NO	1993	317	4,218	4,535	93.0%
		1994	797	3,870	4,667	82.9%
		1995	1,208	2,665	3,873	68.8%
		1996	2,269	4,384	6,653	65.9%
		1997	145	1,852	1,997	92.7%
		1998	458	3,288	3,747	87.8%
		1999	735	4,759	5,493	86.6%
		2000	592	4,474	5,066	88.3%
		2001	403	5,906	6,309	93.6%
AI	Northerns	2002	347	3595	3943	91.2%
		2003	188	4393	4582	95.9%

Table 12.4. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1974-2003.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls
1974					
1975					
1976					
1977	1202	16	230	224**	11
1978	759	11	148	148**	13
1979					
1980					
1981					
1982	334**	5			
1982					
1984	703**	4			
1985	12**	9	12	0	7
1986	100**	2	100	0	2
1987	976**	9	79	0	3
1988					
1989	80**	1	80	0	1
1990	403**	11			
1991	145**	8			
1992					
1993	1809**	16			
1994	767**	8			
1995	833**	14			
1996	4554	68			
1997	1**	1			
1998	543	14	30	29**	5
1999	917	42	50	0	24
2000	976	68	166	165*	48
2001	661	70	136	0	59
2002	889*	68	200	195*	60
2003	1362	124	318	317*	110

*Used to create age composition
**Not used

Table 12.5. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

YEAR	Aleutian Islands Management Sub-Areas western	central	eastern	EBS estimates southern BS	Total
1980					43,653 (1.33)
1983					44,974 (0.34)
1986					181,056 (0.40)
1991	146,403 (0.21)	64,202 (0.18)	4,068 (0.52)	582 (0.63)	215,255 (0.16)
1994	70,669 (0.61)	15,832 (0.58)	5,933 (0.54)	855 (0.60)	93,289 (0.47)
1997	65,492 (0.38)	18,363 (0.55)	3,331 (0.58)	204 (0.68)	87,390 (0.31)
2000	142,393 (0.39)	37,949 (0.44)	24,957 (0.70)	49 (0.40)	205,348 (0.29)
2002	134,519 (0.33)	38,189 (0.43)	3,242 (0.42)	290 (0.67)	176,240 (0.27)
2004	147,584 (0.28)	27,612 (0.39)	10,375 (0.37)	5,980 (0.93)	191,551 (0.22)
Average (1991-2004)	117,843	33,691	8,651	1,327	161,512
Percentage	73.0%	20.9%	5.4%	0.8%	

Table 12.6. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2004, with the number of hauls from which these data were collected.

Year	**Lengths**	**Hauls**	**Otoliths read**	**Hauls**
1991	4853	47	456	14
1994	6252	118	409	29
1997	7554	153	652	68
2000	7779	135	725	92
2002	9273	141	259	69
2004	12176	201	NA	NA

Table 12.7. Aging error matrix for BSAI northern rockfish, based upon data from Courtney et al 1999.

True age	Observed age: 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	0.89	0.50	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.10	0.38	0.38	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.11	0.38	0.37	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.01	0.11	0.37	0.37	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.01	0.12	0.37	0.36	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.01	0.12	0.36	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.12	0.35	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.35	0.34	0.14	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.34	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.32	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.32	0.32	0.15	0.04	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.14	0.32	0.31	0.15	0.04	0.01	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.30	0.15	0.04	0.01
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.30	0.16	0.05
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.29	0.16
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.29	0.29
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.21	0.50

Table 12.8. Sample sizes of read otoliths by area and year in the Aleutian Islands surveys.

	Area				
Year	Western AI	Central AI	Eastern AI	Southern Bering Sea	Total
1980	0	0	0		0
1983	0	0	0	0	0
1986	132	293	25	115	565
1991		243	159	54	456
1994	180	61	127	41	409
1997	234	219	199		652
2000	229	275	200	21	725
2002	88	74	66	31	259

Table 12.9. Transition matrix for BSAI northern rockfish, showing the proportion of a given age group expected in each length group.

Length (cm)	Age 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
15	0.60	0.16	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.15	0.11	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.11	0.14	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.07	0.16	0.09	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.04	0.15	0.12	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.02	0.12	0.15	0.08	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.01	0.08	0.15	0.12	0.06	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.05	0.13	0.14	0.09	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.02	0.10	0.15	0.12	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.01	0.07	0.13	0.14	0.10	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
25	0.00	0.00	0.04	0.11	0.14	0.13	0.09	0.07	0.05	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
26	0.00	0.00	0.02	0.08	0.13	0.14	0.12	0.09	0.07	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
27	0.00	0.00	0.01	0.05	0.10	0.13	0.13	0.12	0.09	0.08	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02
28	0.00	0.00	0.00	0.02	0.07	0.11	0.13	0.13	0.12	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04
29	0.00	0.00	0.00	0.01	0.04	0.09	0.12	0.13	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.05
30	0.00	0.00	0.00	0.00	0.02	0.06	0.09	0.12	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.06
31	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.08
32	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.09	0.11	0.11	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09
33	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10
34	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.15	0.20	0.26	0.30	0.34	0.38	0.41	0.43	0.45	0.47	0.48	0.52

Table 12.10. Predicted weight and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	52	0.021
4	91	0.030
5	137	0.044
6	185	0.065
7	233	0.093
8	278	0.132
9	321	0.185
10	359	0.252
11	393	0.333
12	423	0.426
13	450	0.524
14	473	0.621
15	492	0.708
16	509	0.783
17	523	0.843
18	535	0.888
19	546	0.922
20	554	0.946
21	562	0.963
22	568	0.975
23	591	0.983

Table 12.11. Negative log likelihood of model components, average effective and input sample sizes, and root mean squared errors for the survey and recruitment residuals.

Component	Negative log likelihood
Recruitment	0.00
AI survey biomass	0.00
Catch	-3.84
F penalty	11.22
Fishery ages	0.00
Fishery lengths	4.72
Survey ages	397.69
Survey lengths	264.98
Prior for *q_srv*	884.26
Prior for *M*	639.55
Prior for σr	0.00
Prior for fish sel slope	0.17
Prior for fish sel 50%	0.00
Total likelihood	2202.12
Average Effective Sample Size	
Fishery ages	33.16
Fishery lengths	9.37
Survey ages	38.58
Survey lengths	99.46
Average Sample Sizes	
Fishery ages	72.67
Fishery lengths	36.83
Survey ages	47.20
Survey lengths	201.00
Root Mean Squared Error	
survey	0.60
recruitment	0.60

Table 12.12. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+)		Spawner Biomass (ages 3+)		Recruitment (age 3)	
	Assessment Year		Assessment Year		Assessment Year	
Year	2004	2003	2004	2003	2004	2003
1977	132,687	137,350	41,067	40,965	28,755	44,538
1978	133,341	137,280	41,843	41,161	23,951	33,136
1979	136,637	139,915	43,393	42,297	25,324	33,818
1980	140,548	143,282	45,045	43,551	33,238	43,988
1981	144,068	146,258	46,695	44,774	23,052	30,760
1982	147,533	149,099	48,337	46,014	22,117	28,736
1983	150,615	151,263	49,892	47,144	22,123	23,936
1984	153,338	152,901	51,403	48,266	17,176	20,408
1985	155,364	153,691	52,797	49,274	14,896	18,722
1986	157,202	154,296	54,122	50,238	20,192	27,705
1987	163,731	157,464	55,395	51,142	117,682	89,381
1988	168,942	159,996	56,575	51,943	34,389	36,725
1989	173,990	162,061	57,706	52,617	22,923	24,451
1990	179,044	164,076	58,775	53,272	24,051	26,353
1991	185,502	166,318	59,633	53,441	79,297	63,803
1992	192,523	169,353	60,636	53,816	52,820	48,985
1993	197,540	170,449	61,165	53,818	21,344	20,964
1994	198,041	167,064	60,979	52,557	17,283	15,370
1995	198,639	163,694	61,285	51,663	24,099	16,740
1996	200,138	162,009	61,777	51,093	44,569	57,444
1997	200,162	157,227	62,222	49,671	64,713	
1998	203,795	157,162	63,856	49,959		
1999	205,443	155,443	64,906	49,659		
2000	204,908	152,010	65,451	48,672		
2001	204,446	149,163	65,846	47,799		
2002	202,279	145,123	65,954	46,390		
2003	202,283	143,604	66,561	45,829		
2004	201,307	141,809	66,896	43,730		
2005	200,013		66,558			

Table 12.13. Projections of BSAI northern rockfish spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 45,912 t and 40,173 t, respectively.

Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	66,815	66,815	66,815	66,815	66,815	66,815	66,818
2005	66,559	66,559	66,956	66,858	67,356	66,406	66,565
2006	65,287	65,287	67,248	66,760	69,267	64,545	65,300
2007	64,183	64,183	67,672	66,797	71,354	62,884	64,059
2008	62,769	62,769	67,719	66,467	73,068	60,955	62,095
2009	61,324	61,324	67,663	66,045	74,675	59,039	60,146
2010	59,895	59,895	67,544	65,575	76,201	57,184	58,262
2011	58,600	58,600	67,486	65,179	77,774	55,500	56,553
2012	57,273	57,273	67,293	64,671	79,157	53,831	54,859
2013	55,973	55,973	67,025	64,110	80,398	52,234	53,236
2014	54,794	54,794	66,793	63,605	81,621	50,794	51,769
2015	53,769	53,769	66,643	63,197	82,882	49,538	50,479
2016	52,900	52,900	66,587	62,898	84,198	48,463	49,364
2017	52,162	52,162	66,607	62,687	85,551	47,545	48,398
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	0.02878	0.02878	0.02878	0.02878	0.02878	0.02878	0.028779
2005	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.048275
2006	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.048275
2007	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2008	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2009	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2010	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2011	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2012	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2013	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2014	0.048275	0.048275	0.024137	0.03007	0	0.057604	0.057604
2015	0.048275	0.048275	0.024137	0.03007	0	0.057603	0.057603
2016	0.048275	0.048275	0.024137	0.03007	0	0.05757	0.057586
2017	0.048275	0.048275	0.024137	0.03007	0	0.057341	0.057445
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2004	5,000	5,000	5,000	5,000	5000.16	5,000	5,000
2005	8,260	8,260	4,178	5,190	0	9,813	8,261
2006	8,044	8,044	4,162	5,142	0	9,472	8,045
2007	7,849	7,849	4,152	5,102	0	9,164	9,330
2008	7,642	7,642	4,129	5,047	0	8,850	9,015
2009	7,452	7,452	4,108	4,996	0	8,564	8,733
2010	7,288	7,288	4,094	4,956	0	8,316	8,488
2011	7,159	7,159	4,092	4,932	0	8,116	8,284
2012	7,042	7,042	4,091	4,911	0	7,936	8,096
2013	6,935	6,935	4,089	4,890	0	7,772	7,921
2014	6,839	6,839	4,088	4,872	0	7,626	7,764
2015	6,755	6,755	4,090	4,858	0	7,499	7,626
2016	6,683	6,683	4,095	4,849	0	7,386	7,505
2017	6,622	6,622	4,102	4,843	0	7,266	7,385

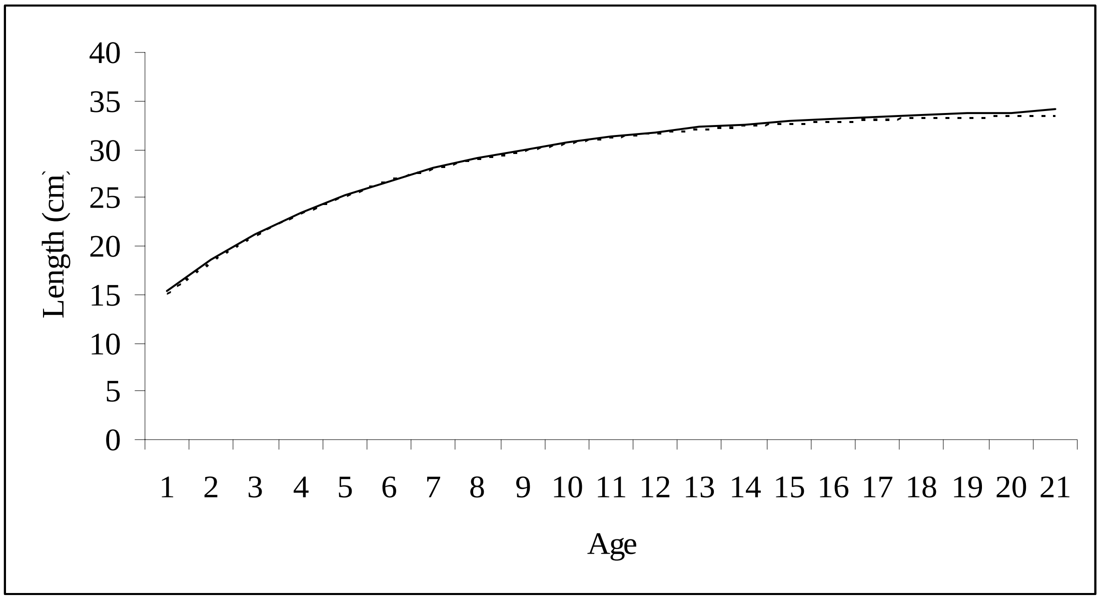

Figure 12.1 Length at age curves used in the 2004 (solid line) and 2003 (dashed line) assessments

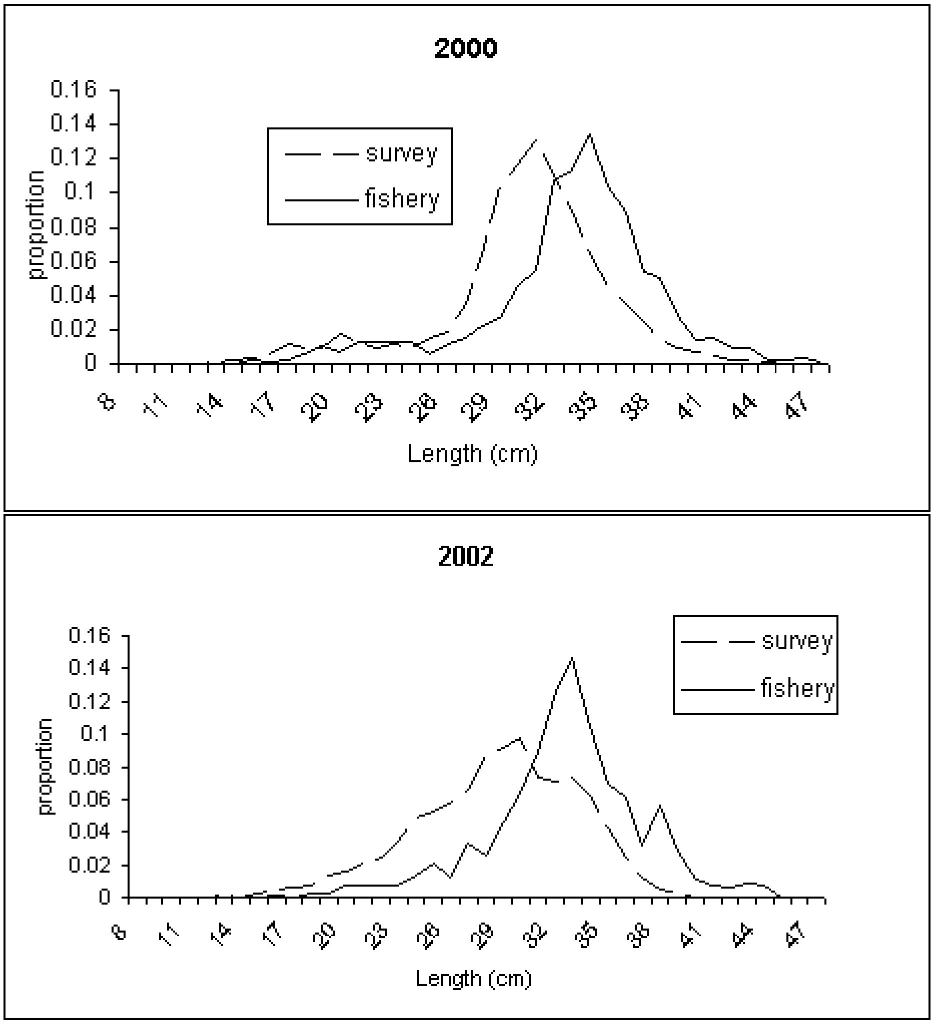

Figure 12.2. Length frequency distribution of northern rockfish from the 2000 and 2002 AI survey and fishery samples.

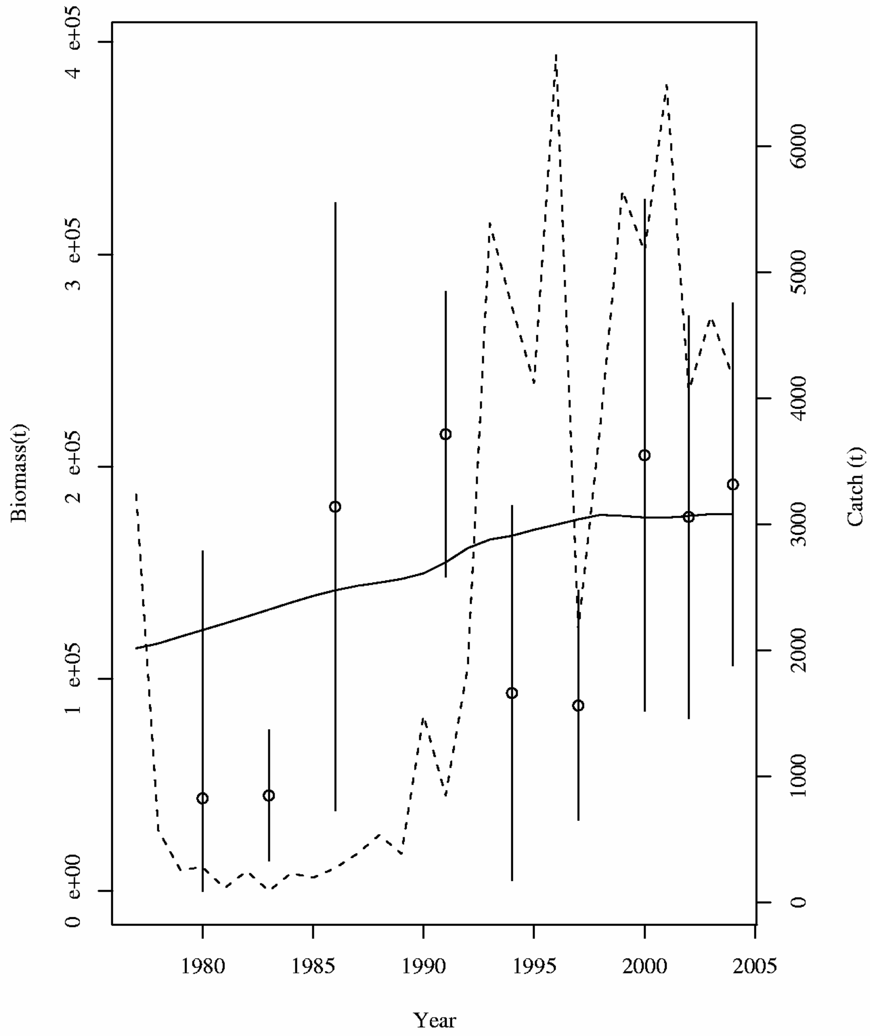

Figure 12.3. Observed AI survey biomass(data points, +/– 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

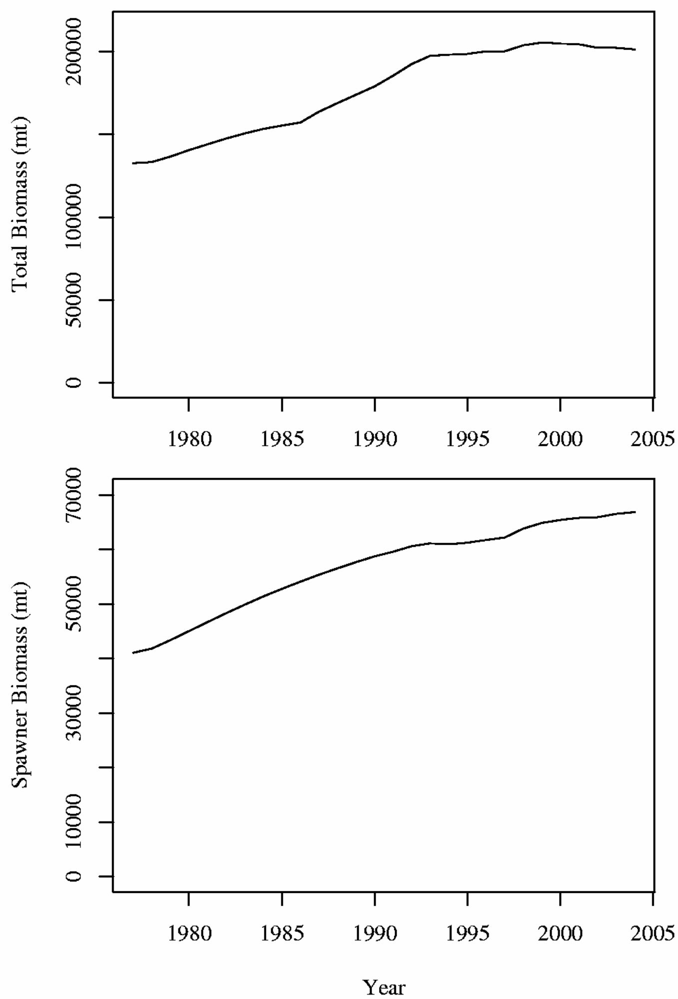

Figure 12.4. Total and spawner biomass for BSAI northern rockfish

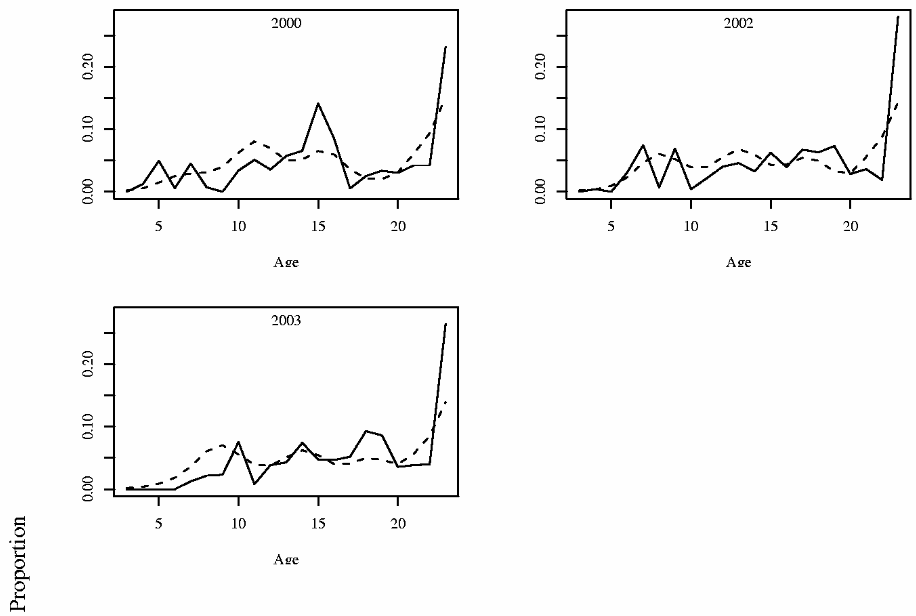

Figure 12.5. Fishery age composition by year (solid line = observed, dotted line = predicted)

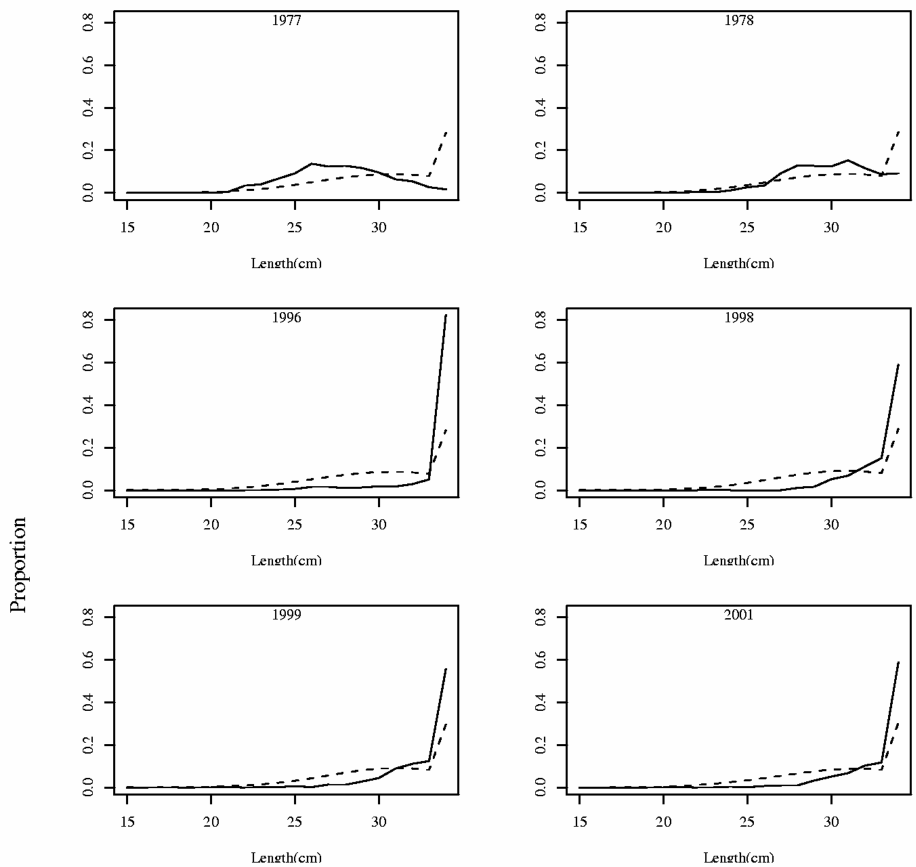

Figure 12.6. Fishery length composition by year (solid line = observed, dotted line = predicted)

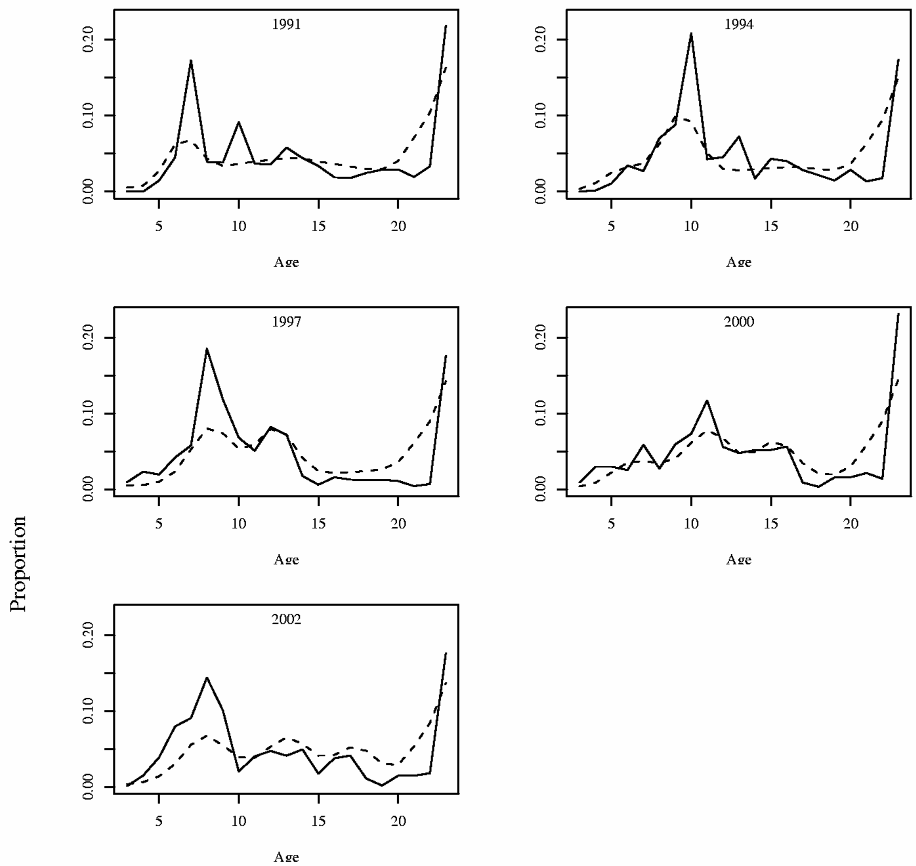

Figure 12.7. AI Survey age composition by year (solid line = observed, dotted line = predicted)

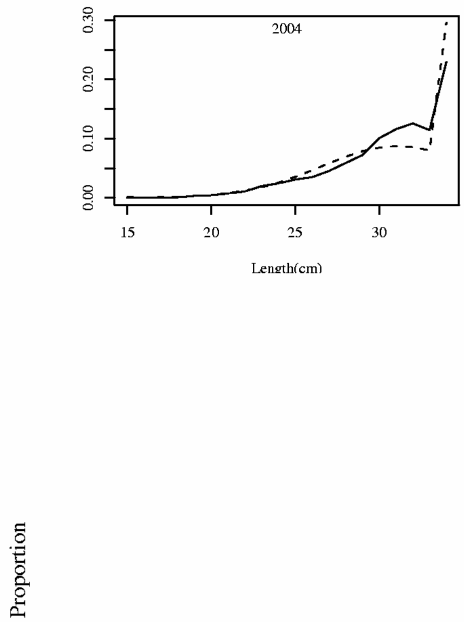

Figure 12.8. AI Survey length composition by year (solid line = observed, dotted line = predicted)

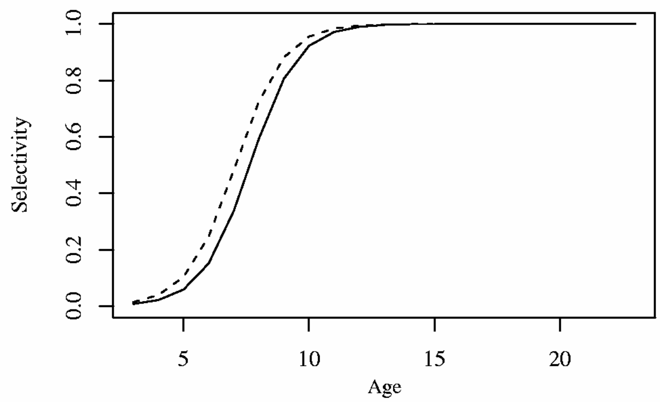

Figure 12.9. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

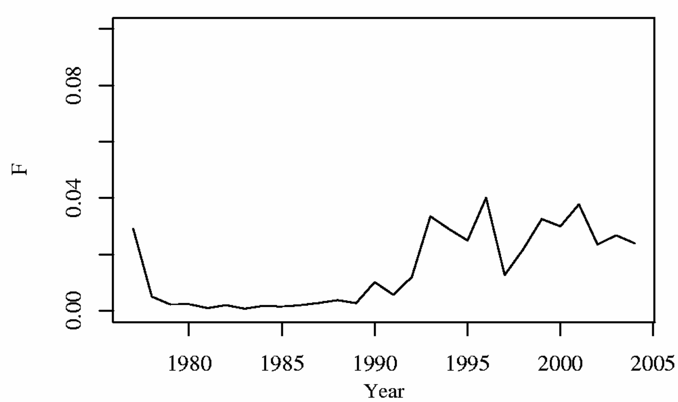

Figure 12.10. Estimated fully selected fishing mortality for BSAI northern rockfish.

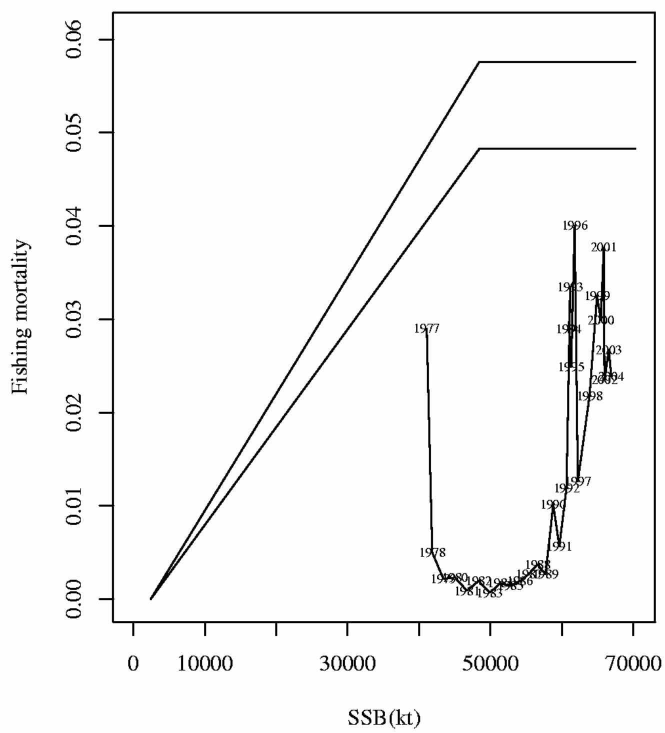

Figure 12.11. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvet control rules

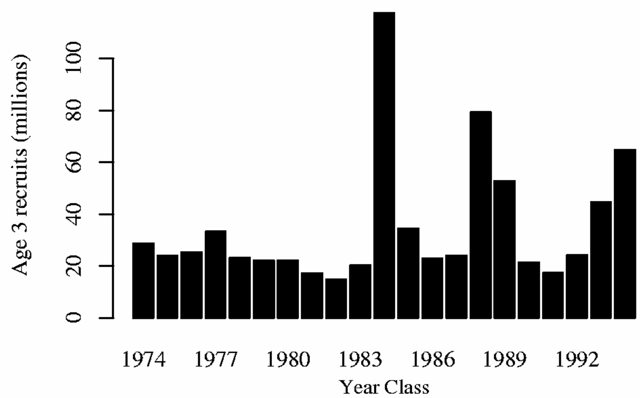

Figure 12.12. Estimated recruitment (age 3) of BSAI northern rockfish